Literature Review on the Greenhouse Effect and Global Warming

by M. English, R.K.W. Wong and B. Kochtubajda

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EXECUTIVE SUMMARY

The public is concerned about greenhouse gases, global warming, and global climate change, yet there is widespread recognition of the uncertainties concerning the science and impacts of climate change. For this reason, the Alberta Research Council undertook, on behalf of the Alberta Department of Energy, the Alberta Department of Environment, the Alberta Oil Sands Technology and Research Authority and the Alberta Research Council, to conduct a literature review of recent (from 1988, 1989, 1990) publications to provide an overview of the degree of consensus on the science of global warming and climate change.

The objectives of the project were to:

1) develop a listing of relevant citations (bibliography) for the period 1980 to 1990

2) review the publication's from 1988, 1989 and 1990, prepare a short summary of the content of each, and develop statistics with respect to the degree to which scientific consensus exists on the various topics of interest.

The bibliography which was developed (Petri, 1990) contains 1557 citations.

A total of 501 publications were reviewed. Publications from known opponents of the global warming issue were specifically included. For each publication reviewed, a questionnaire which addresses the key concerns of government and industry was completed and the questionnaires were analyzed to produce the statistics that show the degree to which scientific consensus exists on the various topics. The topics of interest are computer modelling of world climate, monitoring of the atmosphere and climate, potential impacts of climate change, potential strategies for responding to climate change, and technological solutions.

Both the bibliography and reviewed papers have been computerized and online searches can be tailored to individual needs. Hard copies of the reviewed papers are available as well. For access, the AOSTRA Library and Information Services should be contacted.

The results show that, with respect to modelling climate and monitoring the atmosphere and climate, a strong consensus exists within the scientific community and those who interpret science, on the magnitude, timing and cause of potential climate change. Strong consensus also exits with respect to some potential impacts, strategies and solutions, especially on a global scale.

Although substantial numbers of papers address the major topics, the review also indicates that the number of papers that deal with important subsets (such as expected climate changes or impacts within a specific region) is quite small.

With respect to Alberta, an increase in average annual temperature of about 5°C, a modest overall increase in total annual precipitation with increases or decreases in specific regions and seasons, and both positive and negative impacts are anticipated by about 2050.

1.0 INTRODUCTION

Greenhouse gases and the potential for global climate change are receiving increased attention by individual countries and in international forums. Many of the options for responding to concerns about global climate change have very significant implications for the production and use of various forms of energy.

At the same time, other air quality issues such as the depletion of the ozone layer, acid deposition, smog, etc. are receiving attention at the international, national and regional levels.

In response to public concern about these issues, the Alberta government has announced the Clean Air Strategy for Alberta initiative, which is jointly managed by the Alberta Department of Energy and the Alberta Department of Environment. Its purpose is to encourage public discussion in Alberta on emissions into the air resulting from the production and use of energy, to help identify and clarify the possible impact of energy-related emissions on the environment and to identify practical and achievable actions that can be taken by producers and consumers to reduce emissions. The Clean Air Strategy for Alberta initiative is to result in a comprehensive, integrated approach to addressing air quality problems in Alberta.

While there is public concern over greenhouse gases, global warming, and global climate change, there is also widespread recognition of the uncertainties concerning the science and impacts of climate change. It is important to the success of the Clean Air Strategy for Alberta that these uncertainties be clarified as much as possible and the information be made available to all who participate.

For this reason, the Alberta Research Council has undertaken, on behalf of the Alberta Department of Energy, the Alberta Department of Environment, the Alberta Oil Sands Technology and Research Authority and the Alberta Research Council, a literature review of recent publications (from 1988, 1989 and 1990) to provide an overview of the degree of consensus on the science of global warming and climate change.

A thorough, scientific review of the timing and magnitude of anticipated global warming has been carried out by the Intergovernmental Panel on Climate Change (IPCC) on behalf of the World Meteorological Organization and the United Nations Environment Program. Their findings were presented to the 2nd World Climate Conference, Geneva, Switzerland in November, 1990. The Alberta Research Council did not attempt to duplicate the efforts of the IPCC. Rather, the Alberta Research Council study documents the diversity of views and the degree of consensus on the various issues related to global warming.

In conducting the literature review, an annotated bibliography was produced (Petri, 1990) along with a summary of the contents of the publications reviewed. The summary is based on a series of questions that were answered for each publication. The project was managed jointly by the four sponsoring organizations.

The methodology used to carry out the literature review, including the criteria used to select the publications, a description of the questionnaire developed to identify and summarize the issues and current scientific consensus, and a description of the analysis performed to quantify the results of the questionnaire, is presented in Section 2. The results from the questionnaire analysis are discussed in Section 3. A summary of the scientific consensus on global warming and climate change emerging from this literature review is presented in Section 4.

2.0 METHODOLOGY

The objectives of the project are to:

1) develop a listing of relevant citations (bibliography) for the period 1980 to 1990;

2) review publications from 1988, 1989 and 1990, prepare a short summary of the content of each, and develop statistics with respect to the degree to which scientific consensus exists on the various topics of interest.

2.1 Bibliography

The bibliography was developed using references from the *Draft Report to Congress of the United States Environmental Protection Agency* (EPA, 1989) and the Canadian Climate Centre's listing of citations (relevant to carbon dioxide and other greenhouse gases) as a base. Additional citations were found through library searches of the United States Department of Energy data base. Originally, it was intended that other data bases be searched as well, however, this was not possible within the available resources.

To ensure some minimum quality in the publications included in the bibliography, only publications from reviewed scientific journals and official government publications were included for the years 1980 to 1988. For the years 1989 and 1990, this requirement was relaxed so that a more comprehensive bibliography could be established for that period. Efforts were made to include publications by known opponents of the global warming issue.

The bibliography was limited to publications that address the key issues of concern to Alberta government officials and industry representatives. These issues are: climate modelling, monitoring of the atmosphere and the climate, potential impacts of climate change, potential strategies for responding to climate change, and technological solutions to the problems created by climate change.

The resulting bibliography is given in Petri (1990) and contains 1557 entries.

2.2 Publications Selected for Review

Publications listed in the bibliography for 1988, 1989, 1990 were reviewed. Short summaries of their contents were prepared. As well, a questionnaire to address the key concerns of government and industry was completed for each. The questionnaires were then analyzed to produce the statistics that show the degree to which scientific consensus exists on the various topics. A listing of the papers reviewed is Appendix A.

Considerable difficulty was experienced in obtaining publications which are not readily available in Alberta. The period between ordering and receiving a publication, in general, was much longer than anticipated. In fact, more than 100 publications ordered early in the study were not received. Furthermore, many publications identified through library searches were found to be not relevant to the key concerns. For example, many deal with methodology without giving any results that are relevant to the questionnaire. As well, obtaining hard copy of publications through library searches was more expensive than anticipated.

2.3 The Questionnaire

A survey questionnaire was developed as a means to provide government officials and industry representatives with an overview of the issues and current scientific consensus that is emerging on global warming and climate change. The questionnaire summarizes information obtained from an extensive literature review. The review only considered contributions from recent (1988-1990) publications including reviewed scientific journals, official government reports, technical reports, and articles from general interest publications, or conference proceedings (see Appendix A).

Questions were formulated in cooperation with the project sponsors. The specific objectives and emerging scientific consensus related to:

a) computer modelling of world climate;
b) monitoring and/or observations of the atmosphere or the climate;
c) the potential impacts of climate change;
d) potential strategies for responding to climate change; and
e) technological solutions.

A sample questionnaire is Appendix B.

The questionnaire is divided into five sections. In the first, the type of publication and the issue(s) addressed are identified. Review papers are identified separately and all the issues covered in the review noted.

In the second section, questions concerning climate modelling are formulated to address the type of emissions, when an effective doubling of greenhouse gases is expected to occur, the predictions (expected for a doubling of greenhouse gases) of future annual temperature and precipitation changes on the global, northern latitude and Alberta climates, and the changes in weather extremes, if any.

The third section addresses the issue of changes in the atmosphere. Specifically, what components are changing? What are the global instrumented observations of temperature and precipitation variations over the past century and decade suggesting? What are the causes of these changes?

In the fourth section, a qualitative assessment of the potential impacts of climate change on various sectors is carried out. These impacts are assessed from a global, Canadian, Prairie, and Alberta perspective.

In the last section of the questionnaire, potential strategies and technological solutions to respond to the threat of potential climate change are identified.

The questionnaire is restrictive in a sense. Although the questions are designed to answer specific needs, there are situations where a paper could be useful without answering the specific questions posed. For example, a modelling paper assessing the cloud feedback effect could imply that many climate models overestimate greenhouse warming. Such results are relevant to the general question of whether there is a greenhouse warming problem, but fail to fit the questions on the questionnaire.

2.4 Analysis of the Questionnaires

The basic analysis of the completed questionnaires considers counts of the various responses. The data base derived from the questionnaires is divided into six categories and the same analysis applied to each of the categories. The categories are:

1) all papers that were reviewed (501 questionnaires)

2) refereed scientific papers only (205 questionnaires)

3) review-type papers only (119 questionnaires)

4) non-review-type papers (382 questionnaires)

5) refereed review-type papers (54 questionnaires)

6) refereed non-review-type papers (151 questionnaires).

One reason for subdividing the papers reviewed was to assess the quality of the results given in the papers. Publications which appear in established scientific journals are generally subjected to peer review prior to publication. This means that they are reviewed by a number of other experts in the field to ensure that no obvious errors were made in obtaining the published results. Such peer-reviewed publications are said to be "Refereed" papers. Categories 2, 5 and 6 contain only these types of publications.

Categories 3 and 4 represent results obtained through a review of research conducted by others. This amounts to a second generation analysis. Such articles are identified as "Review-Type" articles and all others are classified as "Non-Review-Type" articles.

Results of the analysis from the subsets of papers are tabulated in Appendix C.

3.0 RESULTS

The number of papers that address the various topics of interest are shown in Figure 3.1. Note that a substantial number -- 119 is the minimum -- address each topic. The greatest number of papers deals with the potential impact of climate change.

Topics Addressed

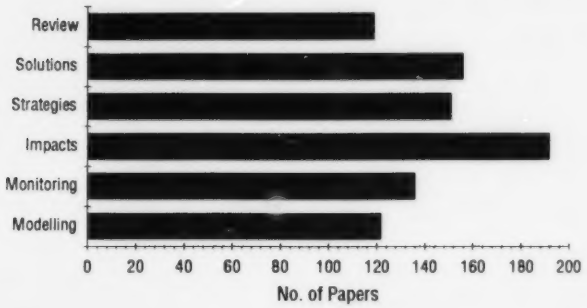

Figure 3.1 Number of papers that address various topics of interest. The topics are: computer modelling of climate, monitoring of the atmosphere and climate, potential impacts of global warming, potential response strategies to global warming, potential technological solutions and a review of the global warming issue.

3.1 Computer Modelling of Climate

There is concern that human activities may be inadvertently changing the climate of the earth and much effort has been devoted to developing computer models that can predict the earth's climate for some future state of the earth/ atmosphere system.

The driving energy for weather and climate comes from the sun. The sun's rays pass through the atmosphere and are absorbed by the earth's surface, which heats up and radiates energy back into space. Some of the gases in the atmosphere capture and hold radiated energy, keeping the surface of the earth warm, much as the glass of a greenhouse keeps the plants inside warm. Without the greenhouse gases such as carbon dioxide (CO_2), all radiated heat would be lost into space and the surface of the earth would be much colder.

The main natural greenhouse gases are not the major constituents of the atmosphere (nitrogen and oxygen) but are water vapour (the greatest contributor), carbon dioxide, methane, nitrous oxide and ozone. By increasing the concentrations of these greenhouse gases and by adding new greenhouse gases like chlorofluorocarbons (CFCs), humankind is capable of raising the earth's temperature. Strictly speaking, this is an enhanced greenhouse effect -- above that occurring due to natural greenhouse gas concentrations.

Changes in solar output, in the earth's orbit, in composition of the atmosphere, and in the surface of the earth are factors which can change the amount of radiation that is emitted to space by the earth/atmosphere system and so change the temperature of the earth's atmosphere and surface.

A change in the earth's surface due to deforestation or desertification affects the amount of solar energy absorbed at the earth's surface. For instance, deforestation has several potential impacts on climate: through the carbon and nitrogen cycles (where deforestation can lead to changes in atmospheric carbon dioxide concentrations), through the change in reflectivity of terrain when forests are cleared, through its effect on the hydrological cycle (precipitation, evaporation and runoff) and surface roughness and thus atmospheric circulation which can produce remote effects on climate. Human-made dust particles, from sulphur emitted largely in fossil fuel combustion, can modify clouds which may affect the earth's temperature. Changes in ozone in the stratosphere due to CFCs may also influence climate.

Water vapour has the largest greenhouse effect, but its concentration in the atmosphere is determined internally within the climate system, and, on a global scale, is not affected by human activities. Water vapour will increase in response to the global warming and further enhance it.

Some greenhouse gases are potentially more effective at changing climate than others. Carbon dioxide is the least effective greenhouse gas per kilogram emitted, but because of the large amounts already in the atmosphere as well as those being emitted daily, it is the greenhouse gas that currently contributes most to global warming.

For a thousand years prior to the industrial revolution, the concentrations of greenhouse gases were relatively constant. However, as the world's population increased and it became more industrialized, and as agriculture developed, the concentrations of greenhouse gases increased markedly. To estimate future climate change, we need to know future greenhouse gas concentrations. These concentrations depend upon the magnitude of human-made emissions and on the exchange of greenhouse gases between the atmosphere, oceans and the earth's ecosystems.

For simplicity, anticipated concentrations of the greenhouse gases are usually expressed in terms of the "Equivalent Carbon Dioxide Concentration" so that the effect on climate is more readily estimated. For each gas the "equivalent carbon dioxide concentration" takes into account its relative effectiveness as a greenhouse gas and the time the gas remains in the atmosphere. Greenhouse gases have increased since pre-industrial times (1765) by an amount equivalent to about a 50 per cent increase in carbon dioxide, although carbon dioxide itself has risen by only 26 per cent.

The best tools currently available for estimating the effect on the earth's climate of increased concentrations of greenhouse gases in the atmosphere are three-dimensional mathematical models of the climate system (atmosphere-ocean-ice-land), known as General Circulation Models (GCMs). GCMs synthesize our knowledge of the physical and dynamical processes in the overall system and allow for the complex interactions between the main components. However, in their current state of development, the descriptions of many of the processes involved are relatively crude. Because of this, considerable uncertainty is attached to the predictions of climate change, which is reflected in the range of values given.

Predictions of future climates are usually expressed in terms of the climate anticipated when the total concentration of all greenhouse gases in the atmosphere is equivalent to a doubling of the pre-industrial (1765) concentration of carbon dioxide.

Global warming may also lead to increased global average precipitation and evaporation. Areas of sea, ice and snow are expected to diminish. Knowledge of the global mean warming and change in precipitation is of limited use in determining the impacts of climate change. For this we need to know changes regionally and seasonally. GCMs cannot yet give reliable regional predictions at the smaller scales demanded for impacts assessments. Changes in the variability of weather and the frequency of extremes will generally have more impact than changes in the mean climate at a particular location.

3.1.1 Results from the Literature Review

Figure 3.2 shows the type of emissions addressed by the publications; the greatest number deal with carbon dioxide emissions. As well, a substantial number of papers address greenhouse gases in general.

Types Of Emissions Addressed

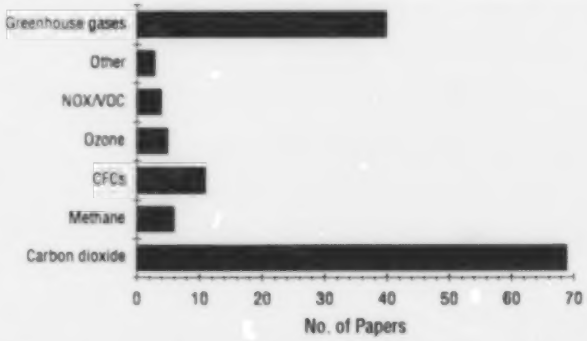

Figure 3.2 Number of papers that address the various types of emissions: emissions of carbon dioxide, of methane, of chlorofluorocarbons (CFCs), of ozone, of nitrogen oxides and volatile organic compounds (NOx/VOC), of other types of emissions (dust particles) and of unspecified greenhouse gas emissions.

With respect to the occurrence of greenhouse gas concentrations equivalent to a doubling of the pre-industrial concentration of carbon dioxide, most publications suggest that this will occur about 2050 (Figure 3.3). It is significant that no publication suggests the effective doubling of pre-industrial carbon dioxide (referred to henceforth as "effective doubling of greenhouse gases") may never occur.

Time Of Effective Doubling Of Greenhouse Gases

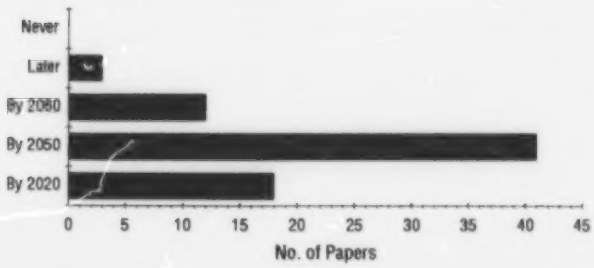

Figure 3.3 Number of papers that suggest that the concentration of greenhouse gases in the atmosphere will be equivalent to a doubling of pre-industrial carbon dioxide by various dates.

With respect to the increase in global temperature anticipated from an effective doubling of greenhouse gases, Figure 3.4 indicates that most of the publications suggest that this increase will be in the range of 3 to 3.9°C. This is in agreement with the results announced recently from the Canadian Climate Centre General Circulation Model (Hengeveld, 1990).

Global Temperature Increase Predicted For An Effective Doubling Of Greenhouse Gases

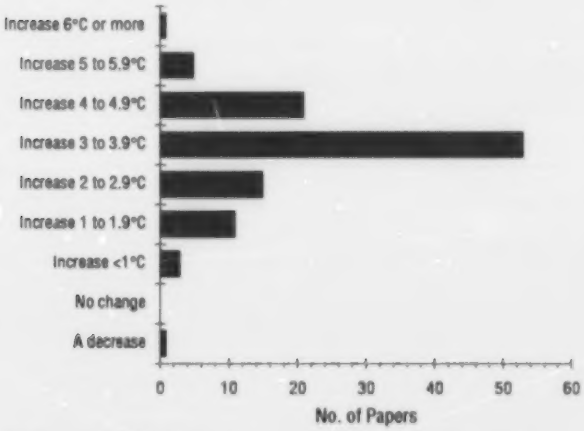

Figure 3.4 Number of papers that suggest the increase in global temperature will be of stated magnitude when the greenhouse gas concentration in the atmosphere becomes equivalent to a doubling of the pre-industrial concentration of carbon dioxide.

Results given in Appendix C show that the refereed, non-review type articles (i.e. the original scientific research) produce a broader spectrum of opinion both with respect to the time and the magnitude of the temperature increase of an effective doubling of greenhouse gases. This is not surprising because a review article might focus on the most widely held positions, ignoring the extremes.

Figure 3.5 indicates that the anticipated warming in northern latitudes due to an effective doubling of greenhouse gases may be as high as, or greater than, 6°C. Only one paper addresses anticipated temperature increases in Alberta; it suggests that in Alberta the anticipated increase in average temperature under an effective doubling of greenhouse gases is in the range of 5 to 5.9°C (Appendix C).

Temperature Increase In Northern Latitudes Predicted For An Effective Doubling Of Greenhouse Gases

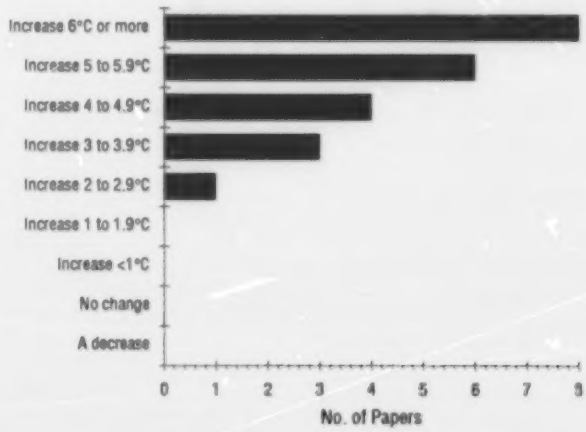

Figure 3.5 Number of papers that suggest that the increase in temperature in northern latitudes will be of stated magnitude when the greenhouse gas concentration in the atmosphere becomes equivalent to a doubling of the pre-industrial concentration of carbon dioxide.

Most papers suggest that an effective doubling of greenhouse gases will result in both increases and decreases in precipitation depending upon location and season with an overall global increase (see Appendix C). Interest in obtaining estimates of precipitation changes stems largely from concern over water availability. To assess impact on water availability, soil moisture and evaporation must be considered along with changes in precipitation. A small portion of the publications (13 of 501) address the topic of weather extremes. These 13 suggest that an enhanced greenhouse effect will cause intensification of weather extremes. Drought frequency might be expected to increase, as would floods. Hurricane intensity might increase and monsoonal circulations strengthen. More intense and stormy conditions could include enhanced winter precipitation in high latitudes, intensified rains in tropical latitudes and perhaps a decrease in summer rainfall in mid-latitudes.

3.2 Monitoring of Greenhouse Gases and Climate

When considering future climate change, it is appropriate to look at the historical record of climate variation. From it we can learn about the range of natural climate variability to see how it compares with what we expect in the future and also look for evidence of recent climate change due to man's activities.

Climate varies naturally on all time scales from hundreds of millions of years down to year-to-year. Prominent in the earth's history have been the 100,000 year glacial-interglacial cycles when climate was mostly cooler than at present. Global surface temperatures have typically varied by 5 to 7°C through these cycles. Since the end of the last ice age about 10,000 years ago, global surface temperatures have probably fluctuated by little more than 1°C.

The instrumental record of surface temperatures is fragmentary until the mid-nineteenth century after which it slowly improves. Because of different methods of measurement, historical records have to be made compatible with modern observations, introducing some uncertainty. Patterns of observed warming show substantial regional diversity (with some regions indicating cooling) which suggests that future regional temperature changes are likely to differ considerably from a global average. The size of the warming over the last century is broadly consistent with the predictions of climate models, but is also of the same magnitude as natural climate variability. The unequivocal detection of an enhanced greenhouse effect from observations of climate is not likely for another decade or more.

Because increases in the concentrations of greenhouse gases in the atmosphere are thought to be likely to produce global warming, it is appropriate to monitor concentrations of such gases as well.

3.2.1 Results from the Literature Review

Out of the 501 papers that were reviewed, 121 address the changing of the earth's atmosphere. With respect to the components of the atmosphere that are changing, the majority address carbon dioxide, as is shown in Figure 3.6

Components Of The Atmosphere That Are Changing

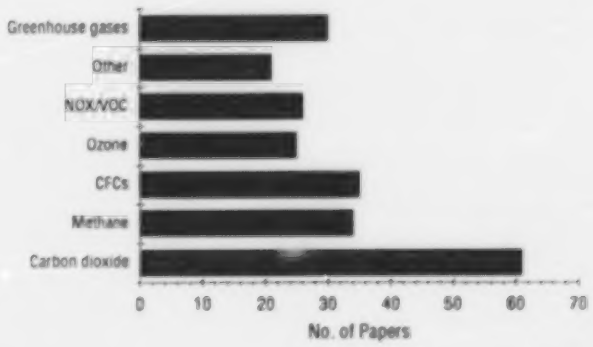

Figure 3.6 Number of papers that suggest the various components of the atmosphere are changing: the concentration of carbon dioxide, of methane, of chlorofluorocarbons (CFCs), of ozone, of nitrogen oxides and volatile organic compounds (NOx/VOC), other components (such as water vapour, sulphur compounds, carbon monoxide, volcanic dust) and of unspecified greenhouse gases.

With respect to monitoring changes in climate, only 80 entries on the questionnaires deal with this subject, most indicate that an increase in temperature has been observed over the past decade and over the past century both at the global and regional scale. However, only a few studies have computed the statistical significance of such observations. No conclusions are generally drawn with respect to changes in precipitation or weather extremes in the past decade or century. Most of the publications that indicate that increases in global temperature have been observed suggest that the observed increases are consistent with a change in the composition of the earth's atmosphere.

3.3 Potential Impacts of Climate Change

Comprehensive estimates of physical and biological effects of climate change at the regional level are difficult. Confidence in regional estimates of critical climate factors is low. This is particularly true of precipitation and soil moisture. Moreover, there are several scientific uncertainties regarding the relationship between climate change and biological effects and between these effects and socio-economic consequences. Finally, the issue of timing and rates of change need to be considered. There will be lags between:

1) emission of greenhouse gases and doubling of concentrations;

2) doubling of greenhouse gas concentrations and changes in climate;

3) changes in climate and resultant physical and biological effects; and

4) changes in physical and ecological effects and resultant socio-economic consequences.

Because of these uncertainties, precise predictions cannot be made with respect to potential impacts of climate change. However, some general conclusions can be reached, even with the current state of knowledge.

Because species respond differently to climate change, some will increase in abundance and/or range while others will decrease. Ecosystems will therefore change in structure and composition. Ecosystem structure and species distribution are particularly sensitive to the rate of change of climate. The rate of projected climate change is likely to be faster than the ability of some species to respond and adapt. In other words, it is likely that there will be winners and losers.

Changes in climate are likely to have an important effect on agriculture. Longer growing seasons and more carbon dioxide in the atmosphere may have a positive effect. But negative impacts could be felt at the regional level as a result of changes in weather, diseases, pests and weeds. An increase in drought risk potentially represents the most serious impact of climate change on agriculture at both the regional and global levels.

With forestry, fire severity may increase. Major forest-type zones and species ranges could shift significantly as a result of climate change. Boreal forests and forests in arid and semi-arid regions are likely to be particularly sensitive. Climate will probably change much faster than tree species can migrate naturally.

Relatively small climate changes can cause large water resource problems especially in arid and semi-arid regions and the humid areas where demand or pollution have led to water scarcity. It appears that many areas will have increased precipitation, soil moisture and water storage, thus altering patterns of agriculture and other water use. In such areas, water management practices such as urban storm drainage systems may require increased capacity. Water availability will decrease in other areas. This has significant implications for agriculture, for water storage and distribution, and for hydroelectric power generation. Water demand may also change.

Major health impacts are possible, especially in large urban areas, owing to changes in water and land availability and increased health problems due to heat stress and spreading of infection. More heat waves could increase mortality. Increased air pollution (closely related to climate change) may adversely affect health. Finally, parasitic and viral diseases have the potential for increase and reintroduction in many countries.

Global warming will accelerate sea-level rise, modify ocean circulation and change marine ecosystems with considerable socio-economic consequences. Permafrost, which underlies 20 to 25 per cent of the land mass of the northern hemisphere, could experience significant degradation within 40 to 50 years. Natural hazards such as coastal or river flooding, severe drought, landslides, severe wind storms and tropical storms may pose an increased threat to human settlements. These changes could result in large migrations of people, leading to severe disruptions of settlement patterns and social instability in some areas over a number of years.

Climate change will also affect the regional distribution of renewable energy resources and the availability of biomass. Also, the energy sector may be affected by response strategies against global warming, such as a policy of emission reduction. This may be among the most significant energy sector impacts in many developed countries, increasing opportunities for technologies that produce less greenhouse gases.

3.3.1 Results from the Literature Review

The publications dealing with potential impacts of climate change were analyzed in two ways: one was on a region-by-region basis, the other on a sector-by-sector basis. Not enough information was available to analyze potential impacts on a sector-by-sector basis within each region. The questionnaire identified four regions: the world, Canada, the Prairies and Alberta. Results for these regions are in Appendix C. In general, mainly negative impacts are anticipated for the world, both positive and negative impacts are anticipated for Canada and the Prairies. Only a few publications deal with impacts in Alberta; these are split between positive and negative impacts.

The questionnaire identified 12 sectors with respect to potential impacts of climate change. Results for the most important of these (from an Alberta perspective) are shown in Figures 3.7, 3.8 and 3.9. The remaining results are in Appendix C.

Potential Impacts On Agriculture Of An Effective Doubling Of Greenhouse Gases

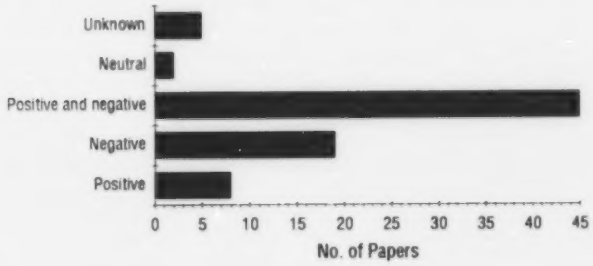

Figure 3.7 Number of papers that suggest positive, negative, both positive and negative, or neutral impacts, or impacts of unknown consequences, on agriculture, from an effective doubling of the pre-industrial concentration of carbon dioxide.

Potential Impacts On Forestry Of An Effective Doubling Of Greenhouse Gases

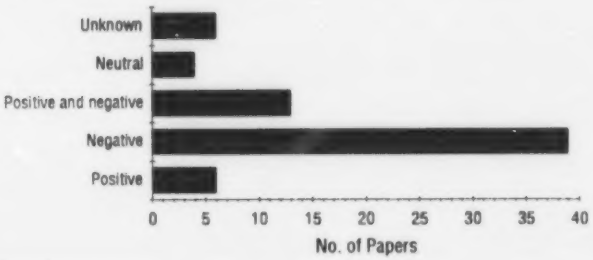

Figure 3.8 Number of papers that suggest positive, negative, both positive and negative, or neutral impacts, or impacts of unknown consequences, on forestry, from an effective doubling of the pre-industrial concentration of carbon dioxide.

Potential Impacts On Health Of An Effective Doubling Of Greenhouse Gases

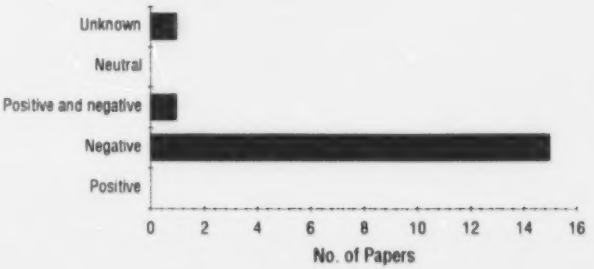

Figure 3.9 Number of papers that suggest positive, negative, both positive and negative, or neutral impacts, or impacts of unknown consequences, on health, from an effective doubling of the pre-industrial concentration of carbon dioxide.

With respect to agriculture, both positive and negative impacts are identified. Mainly negative impacts are indicated for forestry and health. For the energy sector, positive and negative impacts are cited. For the economy as a whole, mostly negative impacts are anticipated.

3.4 Potential Response Strategies

A wide range of human activities results in the release into the atmosphere of greenhouse gases, particularly carbon dioxide, methane, CFCs, and nitrous oxide. Anthropogenic (man-made) emissions can be categorized as arising from energy production and use, non-energy industrial activity (primarily the production and use of CFCs), agricultural systems and changes in land-use patterns (including deforestation and biomass burning). Greenhouse gas emissions from most sources are likely to increase significantly in the future.

Because climate change could potentially result in significant impacts on the global environment and human activities (Section 3.3), it is important to begin considering what response measures might be taken. A wide range of options is available including measures both to limit net greenhouse gas emissions (limitation strategies) and to increase the ability of society to adapt to a changing climate (adaptation strategies).

The consideration of climate change response strategies, however, presents formidable difficulties for policy makers because the available information is inadequate. For instance, scientific uncertainties remain regarding the magnitude, timing, rate, and regional consequences of potential climate change. Uncertainty exists as to how effective specific response options would be in averting potential climate changes. It also exists regarding costs, effects on economic growth, and other economic and social implications of specific response options. These uncertainties can be reduced through accelerated and coordinated research programs on the scientific and socio-economic aspects of the issue and through increased monitoring of greenhouse gas concentrations, of the climate, of sea level and the extent of snow and ice covers.

There are also some response options that may be economically and socially feasible to implement in the near-term, while others, because they are not yet technically or economically viable, may be more appropriate in the longer term. The degree to which options are viable will vary considerably depending on the region or country involved.

Options for limiting net emissions of greenhouse gases (limitation strategies) include measures which limit emissions from greenhouse gas sources and which increase the use and protection of natural repositories for absorbing greenhouse gases, such as forests.

Various options have been identified for reducing greenhouse gas emissions:

- efficiency improvements and conservation in energy supply, conversion, and end use in existing and new facilities;
- fuel substitution to energy sources which have lower greenhouse gas emissions;
- reduction of greenhouse gas emissions by removal and capture;
- elimination of the use of CFCs;
- improved management of livestock feeding and wastes, fertilizer use and agricultural practices, improved land use (e.g. reforestation or afforestation), improved forest management, improved waste management (e.g. development of methane recovery systems for landfill and wastewater treatment facilities);
- changes in lifestyle.

Because it is believed there will be a lag time between emissions and subsequent climate change, the climate may already be committed to a degree of change. Implementation of adaptation strategies may be necessary regardless of any limitation actions which may be taken.

Adaptation strategies can be divided into two broad categories:

- coastal zone management (options which maximize the ability of coastal regions to adapt to the projected sea level rise and to reduce vulnerability to storms); and
- resource use and management (options which address the potential impacts of global climate change on food security, water availabiiity, natural and managed ecosystems, land, and biodiversity).

3.4.1 Results from the Literature Review

In the publications reviewed, limitation strategies are suggested, in general, for emissions of carbon dioxide, methane, CFCs, ozone and nitrogen oxides, and volatile organic compounds. Figure 3.10 shows that carbon dioxide is most frequently cited for limitation strategies

Suggested Emission Limitation Strategies In Response To Global Warming

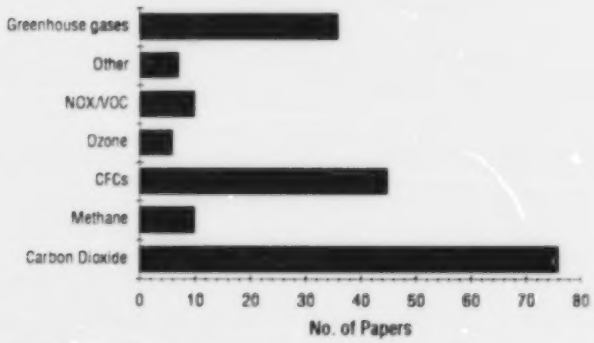

Figure 3.10 Number of papers that suggest limitation of emissions of various gases in response to global warming: the gases are carbon dioxide, methane, chlorofluorocarbons (CFCs), ozone, nitrogen oxides and volatile organic compounds, other gases (mainly sulphur compounds) and unspecified greenhouse gases.

With respect to adaptation strategies (Appendix C) water resource management, agriculture and coastal policies are the sectors most often cited for the development of adaptation strategies.

3.5 Technological Solutions

The application of existing and new technologies is vital to any effort to address global climate change. There will be a need to: limit or reduce anthropogenic greenhouse gas emissions; absorb such gases by protecting and increasing sinks; adapt human activities and resource use and management to the impacts of climate change; and detect, monitor and predict climate change and its impacts. Technological development could be pursued in a wide range of activities such as energy, industry, agriculture, transport, water supply, coastal protection, management of natural resources, and construction.

3.5.1 Results from the Literature Review

The publications reviewed deal mostly with technological solutions applicable to the energy sector such as energy efficiency, fuel substitution, carbon dioxide capture and clean combustion. Reforestation and technology related to landfills are technological solutions mentioned for other economic sectors. Some publications even mention long shots such as climate modification -- the dispersion of dust in the stratosphere to reflect incoming solar radiation. Figure 3.11 shows that simple options such as energy efficiency and fuel substitution, which are economically attractive even now, are suggested most frequently. Note that fuel substitution includes the nuclear option.

Suggested Technological Solutions In Response To Global Warming

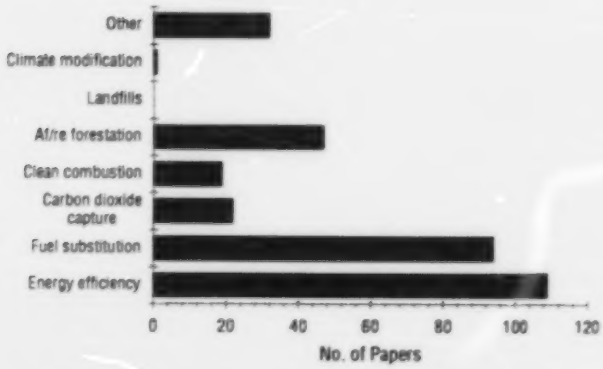

Figure 3.11 Number of papers that suggest the various technological solutions to global warming: the technological solutions are energy efficiency, the substitution of "cleaner" fuels, the capture of carbon dioxide emissions, cleaner combustion techniques, reforestation or afforestation (to increase carbon dioxide sinks), technology for capturing gases from landfills, climate modification (the distribution of dust in the stratosphere to reflect solar radiation), and other technologies (eg. recycling, research and development in general).

4.0 SUMMARY

A total of 501 recent (1988 to 1990) publications have been reviewed. These publications comprise a reasonably representative sample that gives fair representation to all sides of the issue even though the sample is not all-inclusive. Topics covered by the sample of publications are: climate modelling, monitoring of the atmosphere and climate, potential impacts of climate change, potential response strategies, and technological solutions.

The results of the review show that, with respect to modelling climate and monitoring the atmosphere and climate, a strong consensus exists within the scientific community and those who interpret science on the magnitude, timing and cause of potential climate change. This is not an issue that has been promoted by a few vociferous champions. The most common position on these topics is summarized in Table 4.1.

Table 4.1

Most Common Positions in the Scientific Community with respect to the Magnitude and Timing of Global Warming

Issue	Most Common Position
Time of effective doubling of pre-industrial carbon dioxide concentrations	2050
Magnitude of anticipated warming under an effective doubling:	
globally	3 to 3.9°C
northern latitudes only	greater than 6°C
Effect on precipitation of effective doubling	both increases and decreases depending upon location
Cause of observed global warming in the past century/decade	observed warming is consistent with enhanced greenhouse effect

Strong consensus also exists about some potential impacts, strategies and technological solutions. These are summarized in Table 4.2.

Table 4.2

Most Common Positions in the Scientific Community with respect to Potential Impacts of and Solutions to Global Warming

Impact/Solution	Most Common Position
Impact on World	strongly negative
Impact on Canada/Prairies	both negative and positive impacts
Impact on Agriculture	both negative and positive impacts
Impact on Forestry	strongly negative
Impact on Health	strongly negative
Adaptation Strategies suggested for	agriculture and water resource management
Limitation Strategies suggested for	carbon dioxide emissions and CFCs
Technological solutions suggested	energy efficiency and fuel substitution

Although substantial numbers of papers address the major topics, the numbers that deal with important subsets soon become quite small. For instance, estimates for global warming under an effective doubling of greenhouse gases is addressed in 111 papers. But the anticipated warming in northern latitudes is addressed in only 20 papers. Only one paper (Wong et al., 1989) deals with the anticipated warming in Alberta.

With respect to Alberta, Wong et al. (1989) suggest that, under an effective doubling of greenhouse gases, on average Alberta will be 5°C warmer than its current normal climate. Two publications suggest that Alberta will have an increase in precipitation under an effective doubling of greenhouse gases and one suggests that there will be increases and decreases, depending upon location and season. Wong et al. (1989) also found that there has been a gradual increase in temperature in Alberta over the past century and a greater overall increase in temperature in the 1980s. With respect to potential impacts in Alberta of an effective doubling of greenhouse gases, both positive and negative impacts are suggested. However, there were only eight references to potential impacts in Alberta.

Of the 501 publications reviewed, 151 are in the category of refereed, non-review-type (i.e. original research) papers which are the primary data set. One interesting result from the analysis is that review-type papers tend to focus on the most popular point of view regarding the timing and magnitude of changes anticipated; the original research papers produce a broader spectrum of opinion.

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APPENDIX A
List Of Citations For Papers That Were Reviewed

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The Impact of Climatic Variations on Agriculture, V 1: Assessments in Cool Temperate and Cold Regions, Section 5, 1990, P 183-195 (13)

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The Impact of Climatic Variations on Agriculture, V 1: Assessments in Cool Temperate and Cold Regions, Section 1, 1990, P 197-218 (22)

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New Scientist, 12 May 1990, P 42-45 (4)

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Agriculture For Meteorology, V 48, 1989, P 163-173 (11)

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Climatic Change, V 15, 1989, P 151-174 (24)

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Oceanus, V 32, N 2, 1989, P 36-43 (8)

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New Scientist, 6 Jan 1990, P 31 (1)

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Environmental Conservation, V 16, N 2, 1989, P 97-99 (3)

World Energy Supply and Greenhouse Effect, by A Rose
Molecular Crystals and Liquid Crystals, V 175, 1989, P 159-168 (10)

APPENDIX B

Literature Review on The Greenhouse Effect
Publication Questionnaire

Is this publication:

- ☐ a reviewed scientific paper
- ☐ an official government report
- ☐ a technical report
- ☐ other type of publication

Does the paper address:

- ☐ computer modelling of world climate
- ☐ monitoring and/or observations of the atmosphere or the climate
- ☐ the impacts of climate change
- ☐ technological solutions
- ☐ adaptation strategies
- ☐ review of the issue

REGARDING COMPUTER MODELLING OF CLIMATE

What type of emissions does the paper address:

- ☐ carbon dioxide
- ☐ methane
- ☐ CFC's
- ☐ ozone
- ☐ NOX/VOC
- ☐ other_____
- ☐ greenhouse gases in general

When is the effective doubling of greenhouse gases expected to occur:

- ☐ by 2020
- ☐ by 2050
- ☐ by 2080
- ☐ later
- ☐ never

What will the effect be on average annual temperature if there is an effective doubling of greenhouse gases:

Global	Northern Latitudes	Alberta	
☐	☐	☐	a decrease
☐	☐	☐	no change
☐	☐	☐	an increase of less than 1 C°
☐	☐	☐	an increase of 1 to 1.9 C°
☐	☐	☐	an increase of 2 to 2.9 C°
☐	☐	☐	an increase of 3 to 3.9 C°
☐	☐	☐	an increase of 4 to 4.9 C°
☐	☐	☐	an increase of 5 to 5.9 C°
☐	☐	☐	an increase of 6 C° or more
☐	☐	☐	both increases and decreases depending on location

What will the effect be on total annual precipitation if there is an effective doubling of greenhouse gases:

Global	Northern Latitudes	Alberta	
☐	☐	☐	both increases and decreases depending on location
☐	☐	☐	no change
☐	☐	☐	on average, no change
☐	☐	☐	on average, an increase in precipitation
☐	☐	☐	on average, a decrease in precipitation

Does the paper address changes in weather extremes?

☐ Yes ☐ No

REGARDING MONITORING

Is the composition of the atmosphere changing?

☐ Yes ☐ No ☐ Possibly

If the composition of the atmosphere is changing, what components are changing:

- ☐ carbon dioxide
- ☐ methane
- ☐ CFC's
- ☐ ozone
- ☐ NOX/VOC
- ☐ other _____
- ☐ greenhouse gases in general

Global			Regional			
Yes	No	Maybe	Yes	No	Maybe	
☐	☐	☐	☐	☐	☐	Over the past century, has there been an increase in average annual temperature
☐	☐		☐	☐		If a temperature increase has been observed in the past century, is it statistically significant
☐	☐	☐	☐	☐	☐	Over the past decade, has there been an increase in average annual temperature
☐	☐		☐	☐		If a temperature increase has been observed in the past decade, is it statistically significant
☐	☐	☐	☐	☐	☐	Over the past decade, has there been a change in precipitation
☐	☐	☐	☐	☐	☐	Over the past decade, has there been a change in weather extremes

Is the observed change in temperature consistent with what would be expected from

- ☐ a change in atmospheric composition
- ☐ a change in solar activity or earth orbit
- ☐ urban warming
- ☐ other causes

IMPACTS

What are the impacts if there is an effective doubling of greenhouse gases in the atmosphere:

+ Positive
- Negative
X Both Positive and Negative
0 Neutral
? Unknown consequences

World	Canada	Prairies	Alberta	
156 ☐	☐	☐	☐	on agriculture
159 ☐	☐	☐	☐	on forestry
☐	☐	☐	☐	on the energy industry
☐	☐	☐	☐	on tourism
☐	☐	☐	☐	on the general economy
☐	☐	☐	☐	on employment
☐	☐	☐	☐	on the fisheries
☐	☐	☐	☐	on coastlines
☐	☐	☐	☐	on health
☐	☐	☐	☐	on food supplies
☐	☐	☐	☐	on global security
☐	☐	☐	☐	on other systems

Strategies/Solutions

Are adaptation strategies suggested for

164 ☐ agriculture
☐ forestry
☐ water management
☐ tourism
☐ coastal policies
☐ other _____

Are limitation strategies suggested for emissions/concentrations of:

170 ☐ carbon dioxide
☐ methane
☐ CFC's
☐ ozone
☐ NOX/VOC
☐ other_____
☐ greenhouse gases in general

What technological solutions are suggested:

174 ☐ energy efficiency/conservation
☐ fuel substitution
☐ carbon dioxide capture
☐ clean combustion
☐ aforestation/reforestation
☐ landfills and novel feeding procedures
☐ climate modification
☐ other _____

APPENDIX C
Complete Results From The Analysis Of The Questionnaires

Topics Addressed

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Modelling	122	71	59	63	29	42
Monitoring	136	78	50	86	22	56
Impacts	192	77	52	140	28	49
Strategies	151	36	33	118	13	23
Solutions	156	37	29	127	10	27
Review	119	54	119	0	54	0

Regarding Computer Modelling Of Climate Type Of Emissions Addressed

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Carbon dioxide	69	42	28	41	15	27
Methane	6	4	3	3	2	2
CFCs	11	6	4	7	1	5
Ozone	5	2	3	2	1	1
NOX/VOC	4	2	2	2	1	1
Other	3	3	2	1	2	1
Greenhouse gases	40	23	28	12	16	7

Regarding Computer Modelling Of Climate When Is The Effective Doubling Of Greenhouse Gases To Occur?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
By 2020	18	7	10	8	4	3
By 2050	41	23	27	14	14	9
By 2080	12	7	5	7	1	6
Later	3	3	2	1	2	1
Never	0	0	0	0	0	0

Regarding Computer Modelling Of Climate Effect On Global Temperature Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
A decrease	1	1	0	1	0	1
No change	0	0	0	0	0	0
Increase < 1°C	3	2	2	1	1	1
Increase 1 to 1.9°C	11	6	8	3	3	3
Increase 2 to 2.9°C	15	10	8	7	4	6
Increase 3 to 3.9°C	53	28	37	16	19	9
Increase 4 to 4.9°C	21	12	14	7	7	5
Increase 5 to 5.9°C	5	2	2	3	0	2
Increase 6°C or more	1	0	0	1	0	0

Regarding Computer Modelling Of Climate Effect On Temperature In Northern Latitudes Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
A decrease	0	0	0	0	0	0
No change	0	0	0	0	0	0
Increase < 1°C	0	0	0	0	0	0
Increase 1 to 1.9°C	0	0	0	0	0	0
Increase 2 to 2.9°C	1	1	0	1	0	1
Increase 3 to 3.9°C	3	2	1	2	1	1
Increase 4 to 4.9°C	4	2	1	3	1	1
Increase 5 to 5.9°C	6	2	3	3	1	1
Increase 6°C or more	8	3	5	3	1	2

Regarding Computer Modelling Of Climate Effect On Temperature In Alberta Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
A decrease	0	0	0	0	0	0
No change	0	0	0	0	0	0
Increase $<1^{\circ}C$	0	0	0	0	0	0
Increase 1 to $1.9^{\circ}C$	0	0	0	0	0	0
Increase 2 to $2.9^{\circ}C$	0	0	0	0	0	0
Increase 3 to $3.9^{\circ}C$	0	0	0	0	0	0
Increase 4 to $4.9^{\circ}C$	0	0	0	0	0	0
Increase 5 to $5.9^{\circ}C$	1	0	0	1	0	0
Increase $6^{\circ}C$ or more	0	0	0	0	0	0

Regarding Computer Modelling Of Climate Effect On Global Total Precipitation Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Increases & decreases	17	13	11	6	8	5
No change	0	0	0	0	0	0
On average no change	1	0	1	0	0	0
On average an increase	10	4	7	3	3	1
On average a decrease	1	0	1	0	0	0

Regarding Computer Modelling Of Climate Effect On Total Precipitation In Northern Latitudes Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Increases & decreases	3	2	0	3	0	2
No change	0	0	0	0	0	0
On average no change	1	1	0	1	0	1
On average an increase	10	6	7	3	5	1
On average a decrease	3	2	1	2	0	2

Regarding Computer Modelling Of Climate Effect On Total Precipitation In Alberta Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Increases & decreases	1	0	0	1	0	0
No change	0	0	0	0	0	0
On average no change	0	0	0	0	0	0
On average an increase	2	1	1	1	1	0
On average a decrease	0	0	0	0	0	0

Regarding Computer Modelling Of Climate Are Changes In Weather Extremes Addressed?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	13	6	4	9	1	5

Regarding Monitoring
Is The Composition Of The Atmosphere Changing?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	118	64	50	68	24	40
No	2	2	0	2	0	2
Possibly	1	1	0	1	0	1

Regarding Monitoring
What Components are Changing?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Carbon Dioxide	61	35	36	25	18	17
Methane	34	18	16	18	6	12
CFCs	35	15	17	18	7	8
Ozone	25	7	11	14	3	4
NOX/VOC	26	9	15	11	6	3
Other	21	14	6	15	2	12
Greenhouse Gases	30	17	18	12	11	6

Regarding Monitoring
Has There Been An Increase In Global Temperature Over The Past Century?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	37	17	23	14	8	9
No	2	2	1	1	1	1
Maybe	2	2	0	2	0	2

Regarding Monitoring
If A Global Temperature Increase Has Been Observed Over The Past Century Is It Statistically Significant?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	2	2	1	1	1	1
No	4	1	2	2	0	1

Regarding Monitoring
Has There Been An Increase In Temperature Of A Region Over The Past Century?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	10	6	1	9	1	5
No	2	2	0	2	0	2
Maybe	0	0	0	0	0	0

If A Regional Temperature Increase Has Been Observed Over The Past Century Is It Statistically Significant?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	1	1	1	0	1	0
No	3	1	0	3	0	1

Regarding Monitoring
Has There Been An Increase In Global Temperature Over The Past Decade?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	13	8	4	9	2	6
No	2	2	0	2	0	2
Maybe	2	1	0	2	0	1

Regarding Monitoring
If A Global Temperature Increase Has Been Observed Over The Past Decade Is It Statistically Significant

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	2	2	0	2	0	2
No	4	1	1	3	0	1

Regarding Monitoring
Over The Past Decade Has There Been A Change In Precipiation Over A Region?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	2	0	0	2	0	0
No	0	0	0	0	0	0
Maybe	2	1	0	2	0	1

Regarding Monitoring
Has There Been An Increase In Temperature Over A Region In The Past Decade?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	7	5	2	5	2	3
No	1	1	0	1	0	1
Maybe	1	0	0	1	0	0

Regarding Monitoring
Has There Been A Change In Weather Extremes Over The Globe In The Past Decade?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	0	0	0	0	0	0
No	0	0	0	0	0	0
Maybe	0	0	0	0	0	0

Regarding Monitoring
If A Regional Increase Has Been Observed Over The Past Decade Is It Statistically Significant?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	3	2	0	3	0	2
No	1	0	0	1	0	0

Regarding Monitoring
Has There Been A Change In Weather Extremes Over A Region In The Past Decade?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	1	0	0	1	0	0
No	0	0	0	0	0	0
Maybe	0	0	0	0	0	0

Regarding Monitoring
Over The Past Decade Has There Been A Change in Global Precipitation?

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Yes	0	0	0	0	0	0
No	0	0	0	0	0	0
Maybe	0	0	0	0	0	0

Regarding Monitoring
Cause of Observed Change In Temperature

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Change in atmosphere	34	17	16	18	5	12
Change in solar activity	3	3	2	1	2	1
Urban warming	7	5	5	2	3	2
Other	5	4	2	3	2	2

Regarding Impacts
Impact On World Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	15	10	10	5	6	4
Negative	169	66	63	106	30	36
Positive & negative	61	34	26	35	15	19
Neutral	5	1	3	2	0	1
Unknown	19	5	9	10	3	2

Regarding Impacts
Impact On Alberta Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	1	0	0	1	0	0
Negative	3	2	0	3	0	2
Positive & negative	3	1	0	3	0	1
Neutral	0	0	0	0	0	0
Unknown	1	0	0	1	0	0

Regarding Impacts
Impact On Canada Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	17	7	2	15	2	5
Negative	27	8	5	22	4	4
Positive & negative	44	11	10	34	3	8
Neutral	4	2	0	4	0	2
Unknown	6	2	0	6	0	2

Regarding Impacts
Impact On Agriculture Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	8	5	5	3	3	2
Negative	19	7	10	9	5	2
Positive & negative	45	22	17	28	10	12
Neutral	2	2	0	2	0	2
Unknown	5	1	2	3	1	0

Regarding Impacts
Impact On Prairies Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	1	1	0	1	0	1
Negative	6	4	2	4	2	2
Positive & negative	14	2	4	10	0	2
Neutral	0	0	0	0	0	0
Unknown	0	0	0	0	0	0

Regarding Impacts
Impact On Forestry Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	6	5	2	4	1	4
Negative	39	14	10	29	5	9
Positive & negative	13	7	2	11	2	5
Neutral	4	1	1	3	0	1
Unknown	6	3	1	5	1	2

Regarding Impacts
Impact On The Energy Industry Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	7	3	1	6	1	2
Negative	9	5	1	8	0	5
Positive & negative	9	2	1	8	0	2
Neutral	0	0	0	0	0	0
Unknown	2	0	1	1	0	0

Regarding Impacts
Impact On Employment Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	1	1	0	1	0	1
Negative	2	0	0	2	0	0
Positive & negative	1	0	0	1	0	0
Neutral	0	0	0	0	0	0
Unknown	0	0	0	0	0	0

Regarding Impacts
Impact On Tourism Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	3	1	1	2	1	0
Negative	6	3	2	4	1	2
Positive & negative	9	1	4	5	1	0
Neutral	1	0	1	0	0	0
Unknown	1	0	0	1	0	0

Regarding Impacts
Impact On Fisheries Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	1	0	0	1	0	0
Negative	3	1	1	2	1	0
Positive & negative	7	3	2	5	1	2
Neutral	0	0	0	0	0	0
Unknown	3	0	2	1	0	0

Regarding Impacts
Impact On The Economy Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	2	0	0	2	0	0
Negative	12	4	4	8	[illegible]	2
Positive & negative	9	2	4	5	2	0
Neutral	0	0	0	0	0	0
Unknown	2	0	0	2	0	0

Regarding Impacts
Impact On Coastlines Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	0	0	0	0	0	0
Negative	41	20	18	23	11	9
Positive & negative	1	1	0	1	0	1
Neutral	0	0	0	0	0	0
Unknown	0	0	0	0	0	0

Regarding Impacts
Impact On Health Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	0	0	0	0	0	0
Negative	15	5	7	8	4	1
Positive & negative	1	0	1	0	0	0
Neutral	0	0	0	0	0	0
Unknown	1	0	1	0	0	0

Regarding Impacts
Impact On Other Systems Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	3	1	1	2	1	0
Negative	45	14	9	36	3	11
Positive & negative	19	8	5	14	2	6
Neutral	1	0	1	0	0	0
Unknown	6	3	2	4	1	2

Regarding Impacts
Impact On Food Supplies Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	3	2	2	1	1	1
Negative	10	3	6	4	2	1
Positive & negative	7	1	4	3	0	1
Neutral	1	0	0	1	0	0
Unknown	0	0	0	0	0	0

Regarding Strategies/Solutions
Sectors For Which Adaptation Strategies Are Suggested

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Agriculture	42	15	17	25	8	7
Forestry	15	7	2	13	2	5
Water management	44	13	17	27	7	6
Tourism	5	2	1	4	1	1
Coastal policies	20	9	11	9	7	2
Other	18	3	7	11	1	2

Regarding Impacts
Impact On Global Security Of An Effective Doubling Of Greenhouse Gases

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Positive	0	0	0	0	0	0
Negative	4	4	2	2	2	2
Positive & negative	1	1	0	1	0	1
Neutral	0	0	0	0	0	0
Unknown	0	0	0	0	0	0

Regarding Strategies/Solutions
Emissions For Which Limitation Strategies Are Suggested

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Carbon dioxide	76	13	20	56	7	6
Methane	10	1	2	8	0	1
CFCs	45	14	19	26	8	6
Ozone	6	0	2	4	0	0
NOX/VOC	10	5	4	6	1	4
Other	7	4	3	4	2	2
Greenhouse gases	36	7	16	20	6	1

Regarding Strategies/Solutions
Technological Solutions Suggested

	All Papers	All Refereed Papers	All Review Papers	Non-Review Papers	Refereed Review Papers	Refereed Non-Review Papers
Energy efficiency	109	20	32	77	8	12
Fuel substitution	94	21	27	67	8	13
Carbon dioxide caputure	22	2	1	21	0	2
Clean combustion	19	3	1	18	0	3
Af/re forestation	47	16	18	29	8	8
Landfills	0	0	0	0	0	0
Climate modification	1	1	1	0	1	0
Other	32	5	7	25	3	2